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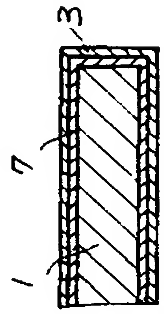
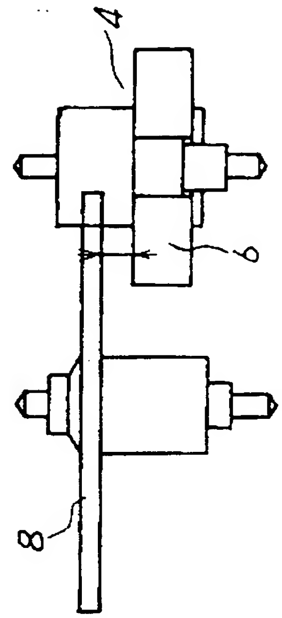
TITLE : ELECTRONIC WRIST WATCH





ABSTRACT : PURPOSE: To eliminate influence of magnetic force so as to normalize movement of a wrist watch and to enlarge degree of freedom in design by forming a nonmagnetic film on a surface of a gear.

CONSTITUTION: A nonmagnetic Ni-P alloy film 7 is formed on the surface of a gear basis 1, said film 7 is covered its surface with an Au film 3 and the gear 8 is obtained. Thereby, the magnetic force generated from a magnet 6 put in a rotor 4 is prevented from attracting the gear 8 and the increase of revolving resistance is prevented.

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(54) DRIVE SYSTEMS FOR ELECTRIC CHRONOMETERS

(71) We, SOCIETE SUISSE POUR L'INDUSTRIE HORLOGERE MANAGEMENT SERVICES, S.A., a Company organized under the laws of Switzerland, of 2500 Bienne, Switzerland, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement: —

This invention relates to drive systems for electric chronometers employing miniature electrical motors designed to be powered by low-output cells or batteries. In conjunction with speed regulators and synchronising devices, these motors are suitable for use in time-measuring processes.

The principal object of the invention is to provide drive systems with low-volume, relatively inexpensive motors which lend themselves to a variety of different horological applications by virtue of the fact that common elements make it possible to manufacture economically various types of constant-speed drive systems which use very little electricity.

More particularly, the invention relates to a type of drive system employing a magneto-electrical micromotor turning at a low regulation speed imposed by a synchronising signal generator, essentially comprising an extremely light multipolar rotor and a stator winding traversed by low-intensity current impulses, the effects of these currents being governed on the one hand by the speed of the rotor and on the other hand by the frequency and the phase of the aforementioned synchronising signal.

It has long been known that the hands of timepieces can be driven by motors designed to function independently, but provided with synchronising devices of the so-called "phase-comparison and phase-blocking" type. For example, the speed of a conventional direct-current motor has been stabilised by means of a correcting device which modifies the motive power in dependence upon the difference between the closure phases of two series-connected circuit breakers one of which is actuated by the rotating armature of the motor and the other by an isochronous electrical tuning fork acting as pilot. However, numerous tests have shown that conventional systems based on this principle are unsatisfactory when applied to small portable instruments such as watches, the loading of the motors in question being provided by mechanical friction or by highly unstable controlling couples.

The problems to be solved are particularly difficult in cases where it is desired to display the time mechanically by means of rotary elements or extremely low volume and in cases where the electrical power required from the energy source is extremely low. This is the case with electronic bracelet watches which have to function with an average electrical power of less than 10 microwatts.

For this application, conventional methods of synchronising rotary motors are attended by the following serious disadvantages:

a) The frictions to be overcome vary considerably when the shaft of the motor occupies different positions in relation to the weight; for example, the passive torque of a rotor weighing a few grams can vary from one to threefold depending on whether the shaft is vertical or horizontal and, as a result, considerably complicates the problem of regulating speed;

b) The loading of the motor is considerably increased when the rotor has intermittently to actuate trip mechanisms such as calendars (day and date appearing in an opening in the face);

c) When the motor is designed in such a way that it is able continuously to overcome the maximum momentary load imposed by the timing mechanism, an excess of motive power is produced in normal operation which can result in racing of the motor and permanent failure of the synchronism;

d) The phase of the rotary movement is modified when the timepiece is suddenly

moved or when it is subjected to impact or heavy vibration; in cases such as these, operation of the motor is seriously affected and the rotor can be "desynchronised" (it is known that this is a frequent occurrence with conventional synchronous motors of the "sound wheel" type whose electromagnetic torque is inverted after slight modification of the phase of the rotor in relation to the phase of the current); such a motor has a rotor in the form of a permanently magnetised polar wheel, with a number of peripheral poles which on rotation induces in the stator a back e.m.f. of sonic frequency;

e) Allowance must also be made for the interference attributable to fluctuations in the speed of synchronised rotors which can be amplified and can cause desynchronisation of the motor;

f) Finally, synchronisation can be adversely affected and interrupted by various causes such as variations in the voltage feeding the motor winding, fluctuations in the ambient temperature and external magnetic fields which can act on the magnetised rotor, different lubricants and clogging of pivots, etc.

The invention proposes to eliminate all these disadvantages by adapting and applying various devices some of which are known but which, hitherto, have never been used in combination and have never given all the results expected.

According to the invention a drive system for an electric chronometer comprises a small magneto-electric motor which includes a low inertia multi-polar permanently magnetised rotor, at least one motor stator winding fed by current pulses, and at least one sensor stator winding generating electrical signals representative of the instantaneous speed and position of the rotor; an electronic synchronisation assembly which includes a quartz oscillator and a multi-stage frequency divider designed to supply low frequency synchronising signals of rectangular form to an associated static switching device; and a main drive circuit fed by a source of continuous potential and including a control transistor or other analogous device which modulates the value of said current pulses feeding the corresponding motor stator winding according to a phase comparison between the signals generated by the sensor winding and said synchronising signals with a view to synchronising the movement of the rotor; said static switching device comprising an auxiliary transistor or analogous device connected before the control transistor with said auxiliary transistor causing, when saturated, short-circuiting of the signals generated by the sensor winding and simultaneous blocking of the control transistor, thereby ensuring complete cut-off of the current pulses which feed the corresponding stator winding.

The accompanying drawings illustrate, purely by way of example, several embodiments of the invention providing improved drive systems and motors in which certain design details have been modified in accordance with the particular conditions of application.

Figure 1 is a sketch completed by a functional circuit diagram illustrating a miniature low-speed rotary motor synchronised by a periodic reference signal supplied by a quartz-crystal oscillator associated with an electronic frequency divider.

Figure 2 shows diagrams illustrating the development with time of the electrical values which modify the duration of the emissions of current generating the propulsive forces of the motor.

Figure 3 is a section taken through the axis of a miniaturised motor functioning by means of brief extremely low currents and designed specifically for telling the time, date and day in a small quartz watch.

Figure 4 is a plan view of one of the plates of the rotor used in the micromotor illustrated in Figure 1, this plate carrying only four magnets of extremely low mass.

Figures 5 and 6 are sections illustrating a modification of the multipolar motor illustrated in Figure 1, the rotor comprising eight prismatic micromagnets of alternate polarity whilst the stator carries four flat coils distributed around the rotor and surrounded by an envelope forming a magnetic covering.

Figure 7 is a perspective view showing the principal components of the motor illustrated in Figures 5 and 6.

Figure 8 is a sketch illustrating a motor which is designed to function in the same way as the motor illustrated in Figure 1 and which can also be used as a step-by-step receiver of high specific power, the structure of this motor comprising a heteropolar rotor with a low moment of inertia provided with five pairs of polar elements, and a polarised stator of high magnetic permeability excited by two long windings wound onto thin cores.

Figures 9 and 10 show the rotor of the motor illustrated in Figure 8 in elevation and in longitudinal section, respectively.

Figure 11 is an axial section and Figure 12 a cross section through a modification of the micromotor shown in Figures 5 and 6 of which Figure 13 shows certain detached components.

Figures 14 to 16 are partially diagrammatic sketches illustrating the application of the invention to the improvement of a conventional timepiece movement of the driven-balance wheel type self-regulated by a transistor.

Figures 17, 18 and 19 illustrate a modification of the motor shown in Figure 8 distinguished by the fact that the rotor comprises 15 pairs of alternate poles and further by the fact that the stator is equipped with

a pick-up and motor winding around a long straight core made of a material of high magnetic permeability.

Figure 20 shows a circuit associated with a frequency divider which only releases extremely low currents.

The right-hand side of Figure 1 shows, in the form of a functional circuit diagram, the components connected to a miniature multipolar motor of the kind described in detail in our French Patent No. 1,535,489, completed by the Patent of Addition No. 2,076,493. This motor is designed to move the hands and the calendar, if any, of a high-precision timepiece. Its rotor is made up of at least one circular plate 1, of iron or soft steel, fixed to a shaft 2 which rotates very freely (a shaft provided with extremely fine pivots guided by stone bearings or by miniature ball bearings not shown in the drawing).

Eight small accurately flat magnets, such as 3, made of a material characterised by an extremely high coercive field H_c and an extremely high energy output HB_{max}, are fixedly arranged at equal intervals around the periphery of the plate 1. The polar faces of the eight magnets are alternatively north (N) and south (S); they pass in front of two flat, fixed windings which comprise numerous conductors of very fine wire which are largely directed radially of the rotor. The first winding consists of a flat pick-up coil BC whose terminals are denoted by the references 4 and 5. The second winding consists of at least two motive flat coils BM_1 and BM_2 mounted in series and connected to the positive terminal of the source G and to the terminal 6. The forms and positions of the coils are selected in accordance with the descriptions and explanations given in French Patent No. 2,076,493. The coils BM_1 and BM_2 form the motor winding receiving emissions of continuous current i_m supplied by a small cell G whose positive and negative terminals are connected respectively to the aforementioned motor winding and to the emitter 7 of a transistor TR (preferably of the NPN-silicon-type) whose collector is connected to the terminal 6.

The end 4 of the pick-up coil is connected on the one hand to the base 8 of the transistor TR and, on the other hand, through a resistance 10 to the positive pole of the source G, whilst the end 5 is connected to the negative pole of the cell through a high resistance 9. The role of this resistance is important, because, where the resistance 9 has a high value, the current that would pass through the circuit (+, 10, BC, 9 and −) in its absence would be substantially eliminated during the non-motive alternations of the motor. The adoption of unusual values that appear abnormally high, such as values of 100 and 200 kilo-ohms, is one of the originalities of the invention; it must be observed to obtain low consumptions of current.

The base 8 of the transistor receives a positive polarisation voltage by virtue of the high-value resistance 10. This polarisation voltage is determined to facilitate periodic establishment of the motive current i_m, although it does not prevent due interruption of this current so that the rotor is acted on by Laplace forces directed in the direction of movement.

The arrangement which has just been summarily described forms a self-contained motor which functions under the conditions specified above. In accordance with the invention, the speed of the rotor is stabilised by adding the following components:

—a miniature quartz (Q) vibrator 11, preferably of constant frequency N_e of a type already in use in quartz chronometers;

—an oscillator circuit 12 which maintains the isochronous vibrations of the quartz by means of the cell G, this circuit further comprising a highly sensitive correcting device for readjusting the pilot frequency N_e (for example a variable capacitor equipped with a slide 13 which enables the user of the timepiece to correct its operation so that the fluctuations amount to less than 0.05 second per day);

—an electronic frequency divider 14 of known type designed periodically to make the synchronising circuit at a submultiple frequency of the pilot frequency N_e of the quartz.

The synchronising circuit of the rotor 1 is obtained simply by connecting the base of the transistor TR to the negative pole of the cell by means of a periodic contactor 15 connecting the conductors 16 and 17 at the low frequency N_s delivered by the divider 14.

In the simplified circuit diagram shown in Figure 1 the control of synchronisation has been shown symbolically by the standard sketch of a mobile contactor designed periodically to short-circuit the conductive elements 16 and 17, although it should be understood that the element 15 is, in reality, a static circuit breaker equipped with semiconductors, for example a bipolar transistor or, preferably, an insulated-gate field-effect transistor. It is known that an electronic circuit breaker of this kind can readily be integrated with a frequency divider of the monobloc type comprising a series of stages for dividing by 2. By virtue of MOS technology, it is readily possible to obtain, at the output end of the element symbolised at 15, short-circuits between 16 and 17 following one another at a constant time interval $T = 1/N$, the duration of each short-circuit being half T_s.

Experience has shown that it is possible to obtain satisfactory synchronisation by selecting the following values which make it pos-

sible to use standardised components manufactured by several electronic component manufacturers: the quartz oscillator 12 vibrates at the frequency $N_e=2^{15}$Hz (or 32 768 Hz); the divider 14 comprises 12 binary stages and delivers at its output a signal of frequency $N_s=2^5$ Hz (or 32 Hz); the electronic circuit breaker 15 connects the base 8 of TR and the negative terminal of the cell G 32 times per second. Under these conditions, the rotor 1, which comprises 4 pairs of poles, assumes a speed which is stabilised at a value of $32/4=8$ revolutions per second.

This result is explained by the diagrams shown in Figure 2.

To analyse operation, we shall first of all assume that the rotor 1 rotates at a substantially constant angular speed $d\alpha/dt$ (α being the angle of rotation which increases as a function of the time t). We shall firstly examine the operation obtained when the synchronising circuit does not come into play, that is to say when the terminals 16 and 17 remain insulated from one another. The lines of flux emanating from the magnets of the rotor (flux parallel to the shaft 2) intersect the radial conductors and induce in the pick-up coil BC an alternating electromotive force of the following form:

$$e_t=(K_1\frac{d\phi}{dt})=(K_1\frac{d\phi}{d\alpha}.\frac{d\alpha}{dt}) \quad (1)$$

In this relation (1), K_1 is proportional to the number of turns of BC and to the number of pairs of poles of the motor. ϕ is the variable magnetic flux contained in the coil BC. During rotation, the variations in the factor $d\phi/d\alpha$ are governed by the width and spacing of the polar faces N, S, N, S . . . of the rotor magnets. When these polar faces are suitably spaced, the curve representing the electromotive force e_t diverges from a sinusoidal form as indicated by diagram (*a*) of Figure 2. It can in effect be seen that the variation with time in the factor $d\phi/d\alpha$ is lower when the empty spaces between the magnets are situated opposite the bundles of radial conductors.

The active circuit comprising the motive coils BM_1 and BM_2 closes when a sufficiently high positive voltage is applied to the base of the silicon transistor TR. On account of the initial polarisation due to the branch containing a well-chosen resistance 10, the motive currents i_m are periodically supplied by the cell when the rotor 1 is turning at a low speed. Distribution of the motive pulses is preferably initiated with minimal base currents i_b and, for this purpose, there is used a pick-up coil BC containing a large number of turns of very fine wire (at most 15 microns in diameter). With all these conditions satisfied, it is possible to release brief pulses of motive currents i_m following one another as shown in diagram (*b*). The periodic spacing T_m of these pulses corresponds to the time which the rotor takes to pass through an angle of 90°, that is to say twice the polar interval NS. The separation width between the motive pulses i_m is governed by the shape of the curve (*a*) and it is possible for the duration δ_1 of each pulse to be substantially shorter than the duration δ_2 of the interruptions in the motive current.

The rotor would be able to turn at the speed required for permanent operation if the passage of the currents i_m could ensure the development of a motive power strictly equal to the opposing power caused by the mechanical losses and by the load on the motor. However, this equilibrium cannot be maintained in practice due to the instability of mechanical friction. In order to be able to regulate the speed, the design parameters adopted are such as to enable a surplus motive power to be obtained when the motive currents are established in accordance with diagram (*b*), and the synchronising device shown on the left-hand side of Figure 1 is brought into play in order opportunely to reduce the durations δ_1 of the motive pulses.

The phenomena which comes into play to regulate speed by means of the quartz are demonstrated in diagrams *c* to *f* of Figure 2 corresponding to the curves (*a*) and (*b*).

The thick horizontal lines in diagram (*c*) represent the half-periods ($T_s/2$ during which the synchronising circuit connecting the terminals 8, 8′, 16, 17 and 7 is closed. The periods during which motive currents i_m are transmitted are governed in duration by the phase difference between the rotation of the rotor and the periodic opening of the synchronising circuit defined above.

For example, diagrams (*d*), (*e*) and (*f*) represent the motive transmissions which always commence at times t_2, t_4, t_6 . . . , these times being governed solely by the synchronising elements 11, 12, 14 and 15. Each transmission of current i_m is interrupted when the positive voltage $+e_s$, generated by the pick-up coil BC, is eliminated. The hatched areas in the drawing represent the amounts of electricity q distributed by the transistor TR in the motive coils BM_1 and BM_2.

In the particular case of operation corresponding to the diagram (*d*), the durations of the transmissions i_m are half the durations indicated in diagram (*c*). The design parameters are selected in such a way that the system of operation (*d*) enables the motive power and the opposing power to be approximately equalised when the motor is functioning normally with a moderate load. Experience has shown that the average speed remains constant, even if the loading of the motor and the mechanical friction vary appreciably.

This regulation of speed emanates from the phenomena described below.

In cases where a reduction in the mechanical friction tends to accelerate the rotor, the periodic spacing T_m of the pulses triggered by the captive coil BC tends to decrease and the durations of the motive pulses decrease progressively as indicated in diagram (*e*). Since the motor receives less electrical power, any increase in speed is automatically limited because a new, stable synchronised condition is established through modification of the phase of the pulses i_m in relation to the fixed timing of the breaks in the synchronising circuit.

An inverse phenomenon comes into play when the load of the motor increases, causing a progressive reduction in the momentary speed of the motor. As shown in diagram (*f*), the motive coils receive gradually increasing quantities of electricity q, with a result that the electrical power increases, thus enabling the initial speed of the motor controlled by the quartz to be re-established. The changes in the loading of the motor are reflected solely in variations of the phase displacement of the rotary movement in relation to the reference signal formed by the periodic interruption of the synchronising circuit.

The sizable modifications of the hatched area q in diagrams (*e*) and (*f*) show that regulation of the speed is guaranteed in spite of the fairly marked variations in the frictional forces and mechanical work generally required of the motor. Other similar phenomena also come into play to stabilise the average speed when the voltage of the cell G undergoes minor variations.

Numerous tests conducted with the arrangement shown in Figure 1 have shown that the establishment of synchronous operation does not necessitate any complicated delicate operations like those used in electrical engineering for "synchronising" conventional synchronous motors: it is sufficient to start the motor at any low speed through a light pulse. At the outset, the period T_m is long in relation to the period T_s of the synchronising action and, under these conditions, the transmissions of current from the cell G are chopped by the closures of the electronic circuit breaker 16—17. However, when the speed of the rotor is low, the counter-electromotive force is itself extremely reduced, resulting in an increase in the intensity of the motive transmissions. Accordingly, the motor is accelerated and it is found that the speed stops increasing and is stabilised when the conditions of operation corresponding to diagram (*d*) are established.

Experience has also shown that the rotor is automatically synchronised when it is started at an exaggerated speed. In this case, the period T_m is shorter than the reference period T_s and the currents i_m are only transmitted at long intervals when the control signals emitted by BC coincide with the breaks in the synchronising circuit. As a result, the motive pulses are not strong enough to maintain high-speed operation. It should also be noted that the currents i_m decrease in intensity when the speed increases; this weakening arises out of the increase in the counter-electromotive force of the motor. The rotor receiving reduced electrical power turns increasing less quickly and spontaneously assumes the regulated system of operation described above in reference to diagrams (*d*), (*e*) and (*f*).

It has been pointed out that, in order to avoid any danger of prolonged racing of the motor shown in Figure 1, it is essential to establish magnetoelectrical components functioning with high electrical efficiency. In normal operation, the counter-electromotive force induced in the winding BM_1—BM_2 by the magnets of the rotor should be fairly close to the voltage of the cell. Once this condition has been satisfied, a slight increase in the speed of the rotor is sufficient to eliminate the current i_m which guarantees rapid return to the synchronous operation analysed earlier on.

When the combination of elements illustrated in Figure 1 is applied to a small, robust horometric instrument designed to perform important functions at periodic intervals (for example to manoeuvre a moving-figure counter or a heavy-duty time switch), it is of advantage to make the motor function normally at maximum specific power. It is known that the mechanical power developed by a magnetoelectrical structure of given volume is at its greatest when the induced counter-electromotive force is half the voltage of the energy source. When the motor works under these conditions, the rotor is in danger of racing because the stabilising effect mentioned earlier on could become inadequate. This danger of racing is also present in cases where the instrument is fed by a battery of accumulators whose voltage, under certain circumstances, can exceed by far the nominal value prescribed for normal operation. The present invention provides a complementary means which completely eliminates the possibility of a break in synchronism caused by an accidental excess of electrical power. This means comprises adding to the elements shown in Figure 1 a safety device, more particularly in the form of a powerful brake which comes into action when the period T_m decreases excessively in relation to the reference period T_s. To absorb the harmful energy, it is possible to employ various systems known *per se*, notably tachometric moderators controlled by the increase in centrifugal force or placing a mechanical oscillator coupled magnetically to the multi-

polar rotor in a state of resonant vibration. For example, it is possible to use devices of the kind described in the article published by M. Lavet in "Annales francaises de chronometrie et de Micromecanique", 1971, pages 75 to 78 (published by Societe Chronometrique de France et de l'Observatoire de Besancon). The design of the brakes added can be simplified because these components do not have to function with great precision when the speed of the rotor increases by 5 to 10% in relation to the speed normally controlled by the quartz standard. Accidental racing of the motor could also be prevented by means of a voltage regulator applied to the motor winding BM_1—BM_2 (a conventional regulator using a non-linear semiconductor) or by a frequency filter of the usual "low-pass" type (with a choke and capacitor) arranged between the pick-up coil BC and the base of the transistor TR. This filter enables distribution of the motive pulses i_m to be suspended in the event of prolonged exceeding of the synchronism speed corresponding to the frequency of the quartz pilot.

In order to facilitate correct starting of the instrument shown in Figure 1, it is provided with a component designed to impart the proper direction of rotation to the motor. This component consists for example of a small snail cam 116 driven by the shaft of the rotor through a gear, and of a leaf 117 acting as a detent pawl.

Figure 3 is a section taken through the axis of a miniature tetrapolar rotor designed specially for electronic bracelet watches. This extremely lightweight rotor consists of two circular plates 18 and 19 preferably less than 7 millimetres in diameter. Each plate forms the highly permeable yoke of four micromagnets 20 which are in the form of accurately flat ring segments or parallelepipeds. The lower plate is shown in plan in the detail view of Figure 4. The plates comprise circular grooves 21 which facilitate positioning of the magnets fixed either by cementing or by welding. These plates are cut out of thin sheet metal (less than two tenths of a millimetre thick) offering an extremely high saturation magnetic flux density. It is possible to employ the known alloy 49 Fe, 49 Co, 2 V, whose saturation flux density reaches 20,000 gauss. Each magnet is less than $2 \times 1 \times 0.5$ millimetres in volume, with a result that they could conceivably be made of an expensive material such as platinum-cobalt alloy or the new samarium-cobalt alloy. The energy output $(HB)_{max}$ of the material selected should be greater than eight-million gauss-oersteds; the short internal lines of force of the magnet should be directed parallel to the axis of the rotor, as indicated by the arrows in Figure 3. The alternate polar faces N, S, N, S should be disposed at 90° as indicated in Figure 4. The flat coils of the stator (BC, BM_1, BM_2) are preferably of the form shown in chain-dot lines in Figure 4. They are less than 1.5 millimetres thick and the flat air gaps are reduced as far as possible. The shaft of the motor equipped with fine pivots (less than 0.1 mm in diameter) comprises a miniature pinion 22 and, preferably, a snail-shaped cam 23 (a so-called "non-return" cam) which cooperates with a light, forked element 24 of non-magnetic material designed to impart the required direction of rotation to the rotor. This element 24 (shown only on the left-hand side of Figure 4) is balanced and turns with considerable freedom in an alternating movement of low amplitude during operation of the motor in the normal direction. It only comes into play when the motor is started for the first time, an operation which is obtained for example by a small movement of the watch.

The micromotor shown in Figures 3 and 4 can be used for showing the time by means of a combination of elements similar to that described earlier on with reference to Figures 1 and 2, although it is preferred to reduce the closure frequency of the synchronising circuit comprising the terminals 16 and 17. The value $2^4=16$ Hz is preferably selected so that the rotor turns at the imposed speed of 8 r.p.s. The pivots are established in the same way as those of conventional watch balance wheels so that friction only produces a loss of less than 1 microwatt. They are preferably protected against shock. In order to reduce the consumption of electricity, windings of very thin enamelled wire are used (diameter less than 25 microns for the driving coils BM_1—BM_2 and, at most, 15 microns for the pick-up coil BC). The resistances 10 and 9 are determined experimentally so that the losses through Joule effect emanating from the currents induced in the coil BC are kept as low as possible. These losses can even be reduced by connecting in series with the resistance 9 a diode which prevents the passage of current during the non-active alternation of the electro-motive force induced in the captive coil BC. In this way, the control signals are interrupted when the terminals 16 and 17 are insulated from one another.

The general characteristics of operation discussed in the preamble of this Specification can be obtained by means of various theoretically equivalent motive structures. For example, Figures 5 to 7 of the accompanying drawings show one modification of the motor illustrated in Figure 1. The fundamental principle is the same, but the rotor is provided around its periphery with 8 micromagnets 25 whose lines of force are radially directed. These magnets are cemented to a small stamped yoke 26 in the form of a cup. This component must be

made of a material of high magnetic permeability. The magnets 25 and the yoke 26 are accommodated in a moulding 27 made of an insulating plastics material of low density. The control pinion 28 can be moulded with the moulding 27, as shown in the perspective view of Figure 7. The casing of the micromotor is with advantage formed by a cylindrical envelope 29 established as shown in the sectional view of Figure 6. This envelope forms a casing which protects the rotor against the external magnetic fields. To this end, it is made of a ferromagnetic substance characterised by the following properties: high permeability, very low coercive field, high resistivity by which it is possible to avoid losses through Foucault currents. For example, the casing 29 is in the form of a small dish obtained by moulding an iron powder agglomerated by an insulating binder. On one side of the casing 29, there is a narrow opening for the passage of the toothed wheel 30 (made of a non-magnetic material) meshing with the pinion 28. The casing 29 carries a removable cover 31 made of extremely soft iron. The fine pivots of the rotor are guided by bearings accommodated in cups integral with the parts 29′ and 31 of the casing.

Four flat coils BM, BM′, BC and BF are cemented to the inner cylindrical surface of the casing 29. These coils form bundles of active conductors parallel to the shaft of the motor and situated at a narrow distance from the multipolar rotor. The width of the middle turns corresponds substantially to the distance between the axes of the two polar faces, north and south. One of the coils is shown in perspective on the left-hand side of Figure 7.

Three of the coils, namely the coils BM, BM′ and BC, perform the same function as the windings illustrated in Figure 1. The additional coil BF can act as a safety brake. For this purpose, its ends are connected to a non-linear resistance which only assumes a low value when the speed of the motor appreciably exceeds the regulation value which has to be imposed by the quartz pilot. Braking emanates from the leakage of energy due to the generation of induced currents by the rapid passage of the rotor magnets.

The intermittent drive torque applied to a multipolar rotor could also be generated by means of coils provided with ferromagnetic cores whose permeability is much higher than that of air. Figures 8, 9 and 10 illustrate a structure of this kind in which the addition of cores highly conductive to the magnetic flux makes it possible to use two long motive coils BM, BM′ and two pick-up coils BC, BC′ of relatively low cost because it is possible to employ an enamelled wire larger in diameter than that of the flat coils used in the motor described above. This wire is simply wound around long linear cores 32 and 33 made of a material characterised by high magnetic permeability and a weak coercive field. In these cores which can be less than one square millimetre in cross section are concentrated the lines of flux generated by the permanent and periodic magnetomotive forces producing the torque of the motor. The cores in question preferably consist of a stack of thin, cut plates coated with an insulating film. It is possible to use annealed alloys based on iron and nickel, for example the alloy known as "Anhyster" manufactured by Acieries d'Imphy (Nievre). The laminated magnetic circuit of the stator comprises two packs of cut plates whose contour makes it possible to obtain two pole pieces 34 and 35 provided with teeth whose shapes are shown in Figure 8. At their lower ends, the parallel cores 32 and 33 comprise transverse extensions 36 and 37 which form a yoke divided into two parts separated by a narrow air gap. A highly coercive cylindrical magnet 38 traversed by lines of force directed parallel to one diameter is inserted at the centre of this yoke. This magnet enables the stator as a whole to be polarised and it is possible to modify the direction and intensity of magnetisation of the cores by changing the direction of the line of the north-south poles indicated by an arrow in the drawing.

The magnetoelectric structure shown in Figure 8 is designed to drive a small-diameter rotor comprising 5 pairs of alternate peripheral poles. This rotor is shown separately on a larger scale in Figures 9 and 10 (which are respectively an elevation and a section on a plane passing through the axis of rotation). The rotor consists essentially of two toothed rings 39 and 40 between which is inserted a bipolar micromagnet 41 in the form of a thin disc whose short internal lines of force are parallel to the axis of rotation. The polar rings are cut out of a thin sheet of iron or ferromagnetic alloy whose saturation flux density is extremely high. The magnet 41 is formed by an alloy characterised by an extremely high coercive field and an extremely high energy output $(HB)_{max}$. It is possible to use either a platinum-cobalt alloy or, preferably, a samarium-cobalt alloy ($SmCo_5$). Although extremely expensive, these materials can be used because the magnet 41 can be given a low volume: for example less than 3 millimetres in diameter and less than 0.5 millimetre thick. The lines of flux emanating from the polar faces of the magnet make it possible to saturate the rings 39 and 40 whose teeth are staggered to form alternate poles.

The small pinion 42 provided with one of the pivots 43 of the rotor is fixed to the centre of the ring 39; the other pivot 44 is carried by the ring 40. The various

·ponents of the rotor are assembled by ·enting to form an extremely lightweight, ..avily magnetised structure which is easy to mass produce and balance.

Experience has shown that the shape of the polar teeth of the rotor plays an extremely important part in the quality and performance of the motor. It has been found to be of advantage to use the tooth form shown in Figure 9. It can be seen that half the end of each tooth is concentric to the axis of rotation and that the other half is slightly eccentric. The polar rings are contoured in such a way that the active periphery of the rotor resembles a continuous circle; the intervals between the sides of adjacent teeth of opposite polarity N and S must be extemely narrow.

As shown in Figure 8, the shape of the inner teeth of the stator should correspond to the outline of the magnetised rings of the rotor. Each pole piece 34 or 35 comprises three polar teeth whose active ends are partly eccentric. In the absence of energising current and under the sole influence of the small polarising magnet 38, the rotor must move spontaneously into one of the positions such that those parts of the teeth concentric to the axis of rotation are located opposite one another. These positions correspond in effect to the minimum reluctance of the air gaps between the rotor and the stator. The magnetic return torque thus obtained is easily regulated to a value that is just sufficient to enable the rotor to be returned to a suitable starting position. However, it is necessary to prevent the rotor from being overstrongly retained by excessive permanent magnetisation of the stator. This magnetisation is readily weakened by changing the orientation of the cylindrical magnet 38 accommodated in the yoke of the stator.

It will be appreciated that the motor thus formed is able to rotate in one direction only in an almost smooth and even substantially uniform movement under the effect of a series of very weak unidirectional current impulses passed periodically through the winding BM—BM'. It is sufficient for the direction of the current and its intensity to be such that the flux which they generate in the coils is opposite in its direction to the polarisation flux and is greater than the latter so as to invert the direction of the magnetic flux in the cores 32 and 33, because reversal of the polarity of the teeth of the stator results in inversion of the direction of the attraction and repulsion forces between the adjacent poles of the stator and rotor. In addition, due to the eccentric shape of the ends of the fixed and mobile polar teeth, rotation is always in the direction of the arrow 45. A brief transmission of current causes the rotor to pass through an angle of 36° and, during the interruption of this current, the small magnet 38 provides for continuity of the movement through 36°, the polar teeth reassuming their relative positions. This operation takes place without interruption when the frequency of the motive pulses is sufficiently high. Accordingly, the motor shown in Figure 8 can be used in the combination of elements described with reference to Figures 1 and 2.

By virtue of the structure shown in Figure 8, relatively high magnetic fluxes can be brought into play by virtue of the high magnetic permeability of the cores of the coils. It is therefore particularly suitable for horometric instruments which require relatively powerful motors (which is the case with timepieces that have to initiate automatic operations such as the sudden displacement of shutters and "type wheels" carrying figures, manipulations of heavy-duty switches, driving heavy hands, printing the time and date, etc.).

The motor shown in Figure 8 also has the advantage that it can be used as a highly efficient step-by-step receiver particularly suitable for repeating the time. It can operate either by impulses or by spaced unidirectional current impulses or by means of inversed currents, for example every second. In the latter case, the magnet 38 can be replaced by a piece of soft iron housed in the yoke 36—37 of the stator.

Figures 11 and 12 are diametral and cross sections, respectively, illustrating a modification of the micromotor described above with reference to Figures 5 and 7. The principle difference concerns the rotor with 5 pairs of alternate peripheral poles. This component is obtained by means of a single bipolar magnet in the form of a flat ring 46. This magnet is made of a material characterised by an extremely high coercive field and an extremely high residual flux density; it is polarised to saturation parallel to the axis of the rotor.

The annular magnet is inserted between two toothed elements 47 and 48 which form two polar rings offset from one another through 36°. These components are cut out of a thin sheet of a ductile ferromagnetic material, for example highly permeable soft steel, or better still of an alloy based on iron-cobalt capable of absorbing and retaining heavy permanent magnetisation under the influence of the coercive ring 46. The ends of the teeth of the polar rings are curved by stamping as shown separately in perspective in one of the views of Figure 13. The shaft of the rotor comprises a collar 46' of fairly large diameter retained between the components 47 and 48 and the elements of the rotor are joined by cementing. It can be seen from the sketches that the curved polar tongues form a circular row of polar faces alternatively north and south, as in the rotor

shown in Figure 7, execpt that the components are easier to assemble. In addition, it is possible in this way to reduce the moment of inertia and the weight of the rotor, above all if a magnet of high quality material, such as $SmCO_5$ is used.

The stator of the motor shown in Figures 11 and 12 is carried by an envelope in two parts 49 and 50 provided with fixing tabs 51 and 52. This envelope is economically obtained by moulding a plastics material (preferably transparent). Arranged inside the envelope 49 in the form of a cup sectional form is the stator winding formed for example by a circular row of 5 or 10 flat coils 53 situated at a narrow interval from the polar faces of the rotor. One of the coils is shown in perspective at the top of Figure 13. It is obtained economically with enamelled wire (wire coated with a thermoplastic varnish bonded after winding simply by heating the winding). Before assembly, it is possible by means of a special automatic machine to manufacture several flat coils 53 connected to one another by the uninterrupted conductor wire which enables the number of welds in the fine wire to be reduced. The stator winding is then cemented into the envelope 49 comprising internal grooves 54 which facilitate positioning of the bundles of active conductors.

The envelope 49 is covered externally by a cover 55 of iron or of iron-nickel alloy which forms a screen or baffle protecting the rotor against the influence of external magnetic fields. This cover also channels the lines of force emanating from the polar teeth 47 and 48 and improves the active magnetic circuits generating the Laplace forces. The inner edge 56 of the yoke 55 can comprise teeth designed to generate a slight magnetically attractive torque acting on the rotor.

The fine pivots of the rotor are preferably guided by caps 57 forming elastic shockproof bearings provided with cushions of a self-lubricating plastics material. One of the pivots is extended and enables a control pinion 58 to be mounted on it. This motor can readily be miniaturised: for example, a multipolar rotor with an external diameter of less than four millimetres can be mass produced.

Figures 14 to 16 show the principal components of a miniature regulated motor designed specially for improving a type of timepiece that is currently in wide use. The balance wheel of these timepieces comprises two yoke plates 59 and 60 fixed to a vertical shaft 61; it causes the horizontal axis 62 of the second hand 63 to progress through a drive-lever transmission which acts on an escapement wheel integral with the pinion 64 meshing with the toothed wheel 65. The plates of the balance wheel are provided with small prismatic bipolar magnets on which acts a flat coil 66 (a coil incorporating a motive winding BM and a pick-up winding BC).

Instead of a helical-spring balance wheel, a timepiece of this kind comprises a drive rotor functioning in the same way as the arrangement shown in Figure 1. This result is readily obtained by cementing two multipolar magnets 68 and 69 in the form of rings to the plates 59 and 60 instead of the bipolar prismatic magnets. One of these magnets is shown in plan view in Figure 15. Eight alternate poles N (north) and S (south) are formed in the flat surface adjacent the coil 66. Although it would of course be possible to cement eight small bipolar magnets of extremely high quality to each plate, as in the rotor of the arrangement shown in Figure 1, it is sufficient, for a relatively voluminous carriage clock, to use magnets consisting of an inexpensive coercive material because the source G of available energy is overabundant; in addition, the surfaces traversed by the magnetic fluxes are larger than in the case of miniaturised rotors. Accordingly, it is possible, for forming the octopolar inductors 68 and 69, to use ordinary washers cut out of a sheet of magnetic rubber. For example, it is possible to use the new material marketed under the name " Ferriflex 4 " (a charged sheet of barium or strontium powder characterised by a coercive field of greater than 2000 oersteds and a remanence of the order of 2500 gauss).

The vertical shaft 61 can be guided by the usual bearings. However, the lower bearing 70 is preferably in the form of a small magnetically repulsive pivot bearing 70. This component, already in use in electricity meters, applies an upwardly directed force very similar in value to the weight of the rotor to a small magnet 71 carried by the shaft 61. On the other hand, the lower end of the shaft 61 is surrounded by a helical spring 72 of stainless steel so as to form an endless screw of low pitch. This screw meshes with a tangential toothed wheel 73 which replaces the escapement wheel of balance-wheel-type carriage clocks. The second hand 63 can thus be driven in a continuous movement through an extremely simple, inexpensive transmission. The other gear trains are not modified.

The windings BC and BM are combined in a flat coil 66 whose average diameter is substantially equal to the distance between two consecutive N and S poles of the rotor. The diameters of the wires are selected to obtain the function analysed above with reference to the diagrams of Figure 2.

The flat coil 66 and the components 11 to 15 (encapsulated quartz, oscillator and frequency divider ...) are fixed to a supporting plate 67 of an insulating material. The connecting circuits can be printed on this plate which can readily be replaced, thus

avoiding difficult and expensive repair work.

It will be noted that the quartz chronometer shown in Figure 16 is largely assembled by means of the tooling already installed for the inexpensive manufacture of balance-wheel-type carriage clocks. Accordingly, the new means described above enable the actual cost of quartz chronometers to be considerably reduced. In addition, the following advantages are obtained over the prior art:

a) the time is shown through a miniature perfectly reliable motor because there is no longer any need for intermittent transmission through a drive lever and escapement wheel (a delicate transmission that is prone to wear and is frequently out of adjustment so that large-radius second hands cannot be correctly actuated);

b) the consumption of energy is greatly reduced because the shaft 61 rotates with minimal losses through friction and does not require the use of an unstable lubricant; it is sufficient to obtain an electrical efficiency e/U of the order of 20% in order to develop on the shaft of the second hand 62 a much higher torque than that permitted by conventional balance wheel movements; in addition, the durations of the motive pulses is automatically regulated to minimal values depending upon the opposing torque applied by the wheel mechanism for the hands;

c) the life of the cell G of standard format can exceed 3 years;

d) operation is completely silent.

The motor shown in Figures 14 and 15 is suitable for wall clocks provided with frames up to 30 centimetres in diameter. It is also possible to make much more powerful movements by making certain changes to the magnetoelectrical components; for example by improving the quality of the magnets 68 and 69, by replacing the single coil 66 by several flat coils arranged as shown in Figure 1, increasing the volume of the cell or using a battery of accumulators. An embodiment thus strengthened is particularly suitable for the following applications and apparatus;

1) direct reading of the time and date by clearly displayed figures and inscriptions jumping suddenly by means of a mechanism of current manufacture;

2) driving heavy wheel trains for the construction of large wall clocks with one or more faces such as public clocks, facade clocks, revolving clocks, information and publicity clocks, large time-indicating boards for sports stadiums . . . ;

3 driving information carriers for recording the time or time intervals, controlling devices which print or announce the time and date (time clocks, watchmen's clocks, parking meters, speaking clocks . . .);

4) switching clocks for changes in rates, programmers, switches timed for prepayment (for hired equipment), chronometric relays equipped with heavy-duty contactors and trip devices;

5) control of automatic decorative clocks;

6) control of clocks equipped with hour and half-hour chimes or bells.

For this latter application, it is possible to use the control principle explained in French Patent No. 444,818 applied for by Ch. O'Keenan on the 10th June, 1912, according to which the wheel train for the hands and the winding mechanism for the bells are actuated by a single, small electrical motor. In this system, the inventor retained a mechanical escapement speed regulator whilst the present invention makes it possible directly to use a regulated, relatively powerful motor rotating at a speed controlled by a periodic signal which can be provided by a high-precision mother clock or by a small quartz-crystal pilot or even by a radioelectrical transmission of standard frequency.

It is possible, without departing from the scope of the invention, to apply various modifications to the electromagnetic structures described above. In particular, the motor shown in Figure 8 could be provided with a larger number of poles which would enable it to function at a relatively low regulation speed (less than 5 revolutions per second). Figure 17 shows by way of example a small motor whose heavily magnetised rotor, although extremely light in weight, comprises 15 pairs of alternate poles. This rotor is shown on a very much larger scale in Figures 18 and 19 (diametral section and elevation, respectively).

As shown by the elevation of the arrangement as a whole in Figure 17, the rotor is almost completely surrounded by a stator comprising two pole shoes 74 and 75 each extending over an arc of approximately 180°. Each pole shoe is provided with five inner teeth whose functions are similar to those performed by the stator teeth of the motor shown in Figure 8. The pole shoes 74 and 75, are connected respectively to a long straight core 76 on which are mounted the coils BM, BC, BM' and BC'. These windings perform the driving and detecting functions explained earlier on with regard to the motors illustrated in Figures 1 and 8. It will be noted that the dimensions adopted (long coils of small diameter) enable the numbers of turns to be increased by avoiding the use of very fine, very expensive conductors. In addition, the losses through Joule effect are reduced. The ferromagnetic parts of the stator are made of plates of alloys based on iron and nickel characterised by high permeability and a very weak coercive field, thus making it possible to increase the density of the flux which is periodically reversed in the core 76.

The rotor comprises two thin polar plates

77 and 78 externally toothed as shown in the drawing. These plates form the flanges of a bipolar magnet in the form of a thin disc 79 preferably formed by the new combination based on samarium and cobalt whose characteristic energy output (BH_{max}) reaches approximately fifteen million gauss-oersteds. With this high quality material, whose coercive force exceeds 5000 oersteds, it is possible considerably to reduce the length of the lines of internal force parallel to the axis of the rotor, so that the polar rings with 15 teeth 77 (north) and 78 (south) are situated at a narrow distance (for example 0.5 mm) from one another. These toothed components are merely cut out of iron or ductile steel and there is no need to curve their ends. They are driven into a seat 80 forming a hub, being offset by half the tooth pitch *p*, that is to say 360°/30=12°. The ferromagnetic parts of the stator can be formed by two packs of thin, cut plates and it is sufficient for the thickness of each pack to be equal to the thickness *ep* of the rotor.

A suitable contour for the teeth is shown in Figures 18 and 19. The width of the teeth is equal to that of the hollows. The outer active surface of each polar tooth is either concentric with the shaft of the rotor or very slightly eccentric, as in the case of the motor shown in Figures 8 to 10. The teeth of the pole shoe 74 are situated opposite the teeth N (north) of the rotor when the teeth of the pole shoe 75 are opposite the teeth S (south) of the rotor. Once these conditions have been satisfied, the motor turns very freely without any interference from the excessive variations in the reluctance of the air gaps between the fixed and mobile teeth.

Normal operation of the motor takes place when the magnetomotive forces of the windings generate a magnetic flux ϕ which is periodically reversed, each reversal of the flux causing the rotor to progress in direction *f* through an angle p/2, *p* being the tooth pitch. When the frequency of the flux reversals is low, the rotor, subjected to a pulsating torque, tends to progress in jerks. Accordingly, there is a danger of parasitic oscillations occurring, like those which interfere with the operation of industrial synchronous motors powered by alternating current. These phenomena are analysed in electrotechnical treatises and it is known that oscillations of this kind can be intensified and can cause desynchronization of the rotor. In order to eliminate this fault, provision has been made to add a damping means known *per se* in the form of a small wheel 81 coaxial with the rotor. This wheel is connected to the multipolar rings by means of a helical spring 82. The wheel can turn in relation to the shaft and, to prevent blocking, it is provided with a hub of self-lubricating material. The maximum angle of rotation of the wheel in relation to the shaft is limited by means of a rod 84 which passes with some clearance through a hole in the driven mass.

Damping of the troublesome speed vibrations is based on the following phenomena: when the electromagnetic motor torque is applied, the rotor 77—78—79 tends to make an accelerated rotary movement, whilst the wheel 81 tends to stay at a uniform speed, with the result that the wheel slides in relation to the shaft of the rotor; sliding in the opposite direction takes place when the electromagnetic torque is interrupted while the wheel continues to rotate. The small sliding movements of the wheel result in friction and variable tension in the helical spring 82. Experience has shown that, although very weak, these effects come into play to reduce the accelerations and to render the speed of the rotor as a whole uniform. It is possible in this way to improve the operational reliability of the synchronised motor and to avoid shocks from the teeth of the pinion 85 on the teeth of the first wheel of the driven mechanism.

In order to improve a small, relatively powerful timepiece based on the principle described earlier on with reference to Figures 1 and 2, it is of advantage to use the display motor shown in Figures 17 to 19 and at the same time to adopt the supply details discussed hereinafter.

The stator comprises two motive coils BM and BM′ and two pick-up coils BC and BC′. In independent operation during a rotation equivalent to half the tooth pitch (p/2), the group of coils BM—BC generates a magnetic flux $+\phi$ acting in a certain direction; during the following rotation equivalent to p/2, the group BM′—BC′ generates a flux $-\phi$ directed in the opposite direction to the preceding flux. As a result, the motive electromagnetic effects act successively on the rotor with extremely short interruptions. In order to obtain synchronisation of the rotor self-controlled in this way, a quartz crystal Q vibrating for example at a frequency of 2^{15}=32 768 Hz is used in association with a device (component 12—14 in Figure 1) dividing the pilot frequency by 2^9 (or 512) and thus supplying a signal of frequency 2^6 or 64 Hz. Functioning at this frequency, a shaping device known *per se* delivers two series of intermittent signals (so-called "square" signals) phase-displaced in relation to one another by half a period and acting respectively on the currents released by the detector coils BC and BC′ of the stator. By virtue of the phenomena analysed above, the rotor 77—78—79, which comprises fifteen pairs of poles, assumes a regulation speed fifteen times lower than the frequency 64 Hz, i.e. 4.266 revolutions per second (or 256 revolutions per minute). It will be noted that the motor receives weak pulses renewed thirty

times per revolution. By virtue of the low speed of the rotor shaft, it is possible to reduce losses through mechanical friction and to ensure perfect maintenance of the pivots. The reliability of the motor is excellent because the durations of the motor pulses are regulated automatically according to the loading of the motor. In addition, parasitic fluctuations in speed are avoided by the damping wheel 81. Accordingly, the system which has just been described is particularly suitable for applications requiring the maintenance of a strictly constant angular speed (driving magnetic tapes, indicating the time to one hundredth of a second, precision measurement of narrow time intervals, etc . . .).

The explanations relating to Figure 2 show that the multipolar motors described above can be self-controlled and synchronised by the arrangement illustrated diagrammatically in Figure 1. It would of course be possible to resort to different electronic circuits giving the same end result, i.e. circuits which, by phase comparison of the movement of the rotor and of the synchronising signal, ensure synchronisation of the rotor at a low frequency N_s in a constant ratio with the pilot frequency N_e of the quartz signal Q or of any other frequency standard. It has been explained that the multipolar rotor, which drives a load without intervention from the synchronising device, generates a signal voltage of periodicity T_m by means of its detector coil BC. This voltage corresponds to a frequency $N_m=1/T_m$ which will be referred to hereinafter as the "free motor frequency". The function of the synchronising device or "synchroniser" is to render N_m equal to the frequency N_s of the reference signal supplied by the divider 14. For this purpose, the synchroniser shortens to a greater or lesser extent the durations of the transmissions of motor currents i_m as shown in diagrams (*d*), (*e*) and (*f*) of Figure 2. Accordingly, the motor components must be designed to supply an excess of mechanical power when the synchroniser is not in operation. It was explained earlier on that, in certain cases, an excessive electrical power can prevent spontaneous establishment of synchronous operation, and reasons were put forward to justify the need to limit the motive power when the frequency N_m of the free motor far exceeds the reference frequency N_s.

In order, in accordance with the invention, to ensure synchronisation in difficult cases, a safety brake is added which reduces the motor torque when the difference $N_m—N_s$ is excessive. This brake can be formed by a vibrating reed or by a passive tuning fork coupled magnetically to the r tor. In this case, the natural frequency of the resonator is determined in such a way that the mechanical resonance is generated when N_m exceeds N_s. Part of the vibrator used as brake can c me into contact with the rotor on completion of stroke and can cause very heavy intermittent friction.

In such horological applications as those where the opposing torque is very low and hardly varies, it can be sufficient to adjust the motor windings such as BM_1 and BM_2 to obtain a limit speed which, by design, provides for self-synchronisation in every case. "Self-synchronisation" in every case means that the motor follows an increasing pattern when it is started with the synchroniser in action and its frequency automatically becomes equal to N_s whereas, if the synchroniser is disconnected and then reconnected, the frequency of the motor which had exceeded N_e decreases to become equal again to the frequency N_e controlled by the quartz crystal.

An adjustment can be obtained by modifying the value of the resistance 9 in series with the pick-up coil BC or even through a resistance connected in series in the power circuit. Tests have shown that it was possible to obtain self-synchronisation in every case with a margin of variation in the adjustment resistance of as much as 250 ohms for a feed supplied under a voltage of 1.5 volt. It is possible in this way automatically to synchronise a horological micromotor to a frequency of 32 Hz, the frequency of the free motor (without synchroniser) being in the vicinity of 50 Hz. On the other hand, the possible margin of variation in the series adjustment resistance corresponds to the voltage modification of the cell feeding the motor.

In order that the current available at the output of the frequency divider need only be very low, for example of the order of 10 nanoamps, the invention introduces an intermediate transistor *tri*, as shown in Figure 20. When the output 16 of the synchronising signal is positive in relation to the negative pole of the energy source, the auxiliary transistor *tri* is saturated and blocks the power transistor TR. The motor is thus out of action. When the signal is at zero potential, the transistor *tri* is blocked and, since the pick-up coil BC is no longer short-circuited, the motor is able to rotate freely.

Experience has shown that it is necessary to introduce between the output 16 and the base of *tri* a fairly high resistance 89 of the order of 600 kilo-ohms in order to prevent the signal from being destroyed. On the other hand, the transistor *tri* has to be brought to the conductivity threshold by polarising it through a bridge of resistances 90 and 91. Experience has shown that the most favourable values are values approaching 600 and 300 kilo-ohms, respectively.

The circuit diagram in Figure 20 also includes a device by which it is possible to improve the efficiency of the motor by reduc-

ing the width $\delta 1$ of the emissions of motor currents i_m shown in diagram (*b*) of Figure 2. This result is obtained by means of capacitors C_1 and C_2: C_1 is connected in parallel with the resistance 9 whilst C_2 is connected between the base and the emitter of the transistor TR. The effect of these capacitors C_1 and C_2 is as follows: C_1 produces a phase displacement which reduces the motor pulse in its rear portion whilst C_2 produces a phase displacement which reduces this pulse in its front portion. The combined effects of the two capacitors thus reduce the duration of the motor pulse and position it between the spaces on either side. The current is thus transmitted only when the counter-electromotive force is high which is very favourable to the increase in the efficiency of the motor.

WHAT WE CLAIM IS:—

1. A drive system for an electric chronometer, comprising a small magneto-electric motor which includes a low inertia multipolar permanently magnetised rotor, at least one motor stator winding fed by current pulses, and at least one sensor stator winding generating electrical signals representative of the instantaneous speed and position of the rotor; an electronic synchronisation assembly which includes a quartz oscillator and a multistage frequency divider designed to supply low frequency synchronising signals of rectangular form to an associated static switching device; and a main drive circuit fed by a source of continuous potential and including a control transistor or other analogous device which modulates the value of said current pulses feeding the corresponding motor stator winding according to a phase comparison between the signals generated by the sensor winding and said synchronising signals with a view to synchronising the movement of the rotor; said static switching device comprising an auxiliary transistor or analogous device connected before the control transistor with said auxiliary transistor causing, when it is saturated, short-circuiting of the signals generated by the sensor winding and simultaneous blocking of the control transistor, thereby ensuring complete cut-off of the current pulses which feed the corresponding motor stator winding.

2. A drive system according to Claim 1, wherein the synchronising signals are applied to the base of the auxiliary transistor, the collector of which is directly connected to the base of the control transistor, whilst the sensor winding of the motor is connected in shunt to the emitter-collector circuit of the auxiliary transistor.

3. A drive system according to Claim 2, wherein a first capacitor is connected in series with the sensor winding of the motor and a second capacitor is connected in parallel with the circuit comprising the sensor winding and the first capacitor.

4. A drive system for an electric chronometer, substantially as herein described with reference to the accompanying drawings.

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Sheet 1

FIG.1

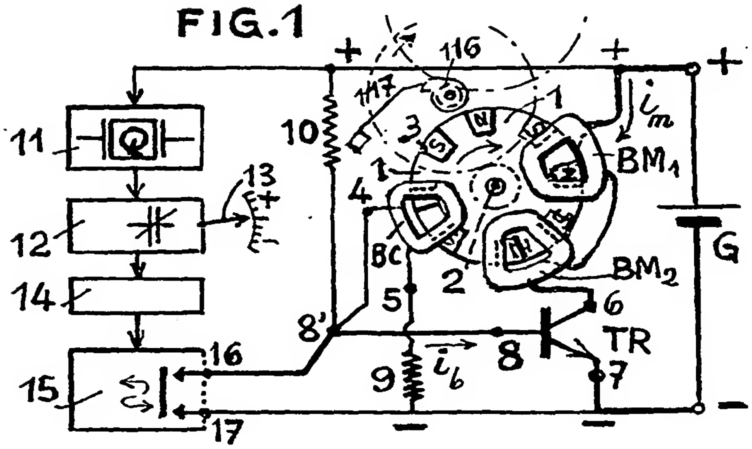
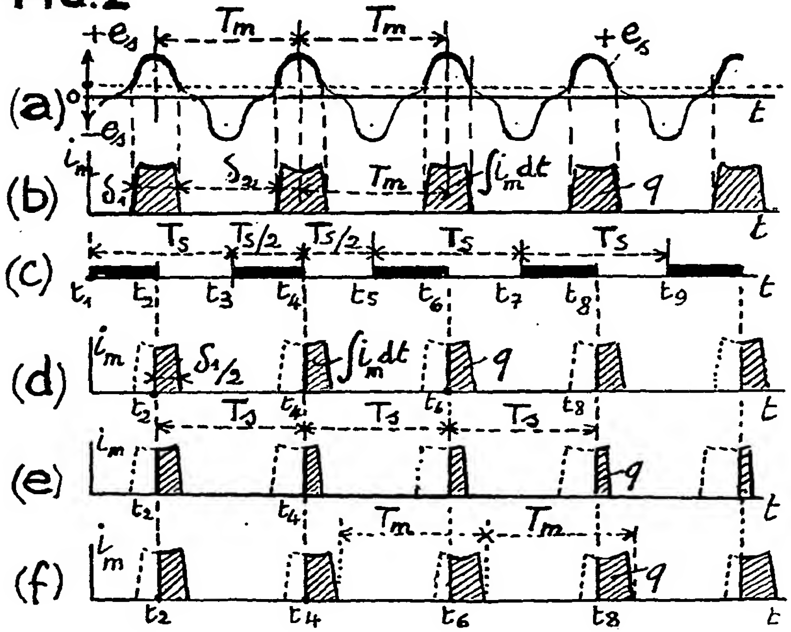


FIG.2



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Sheet 2

FIG.3

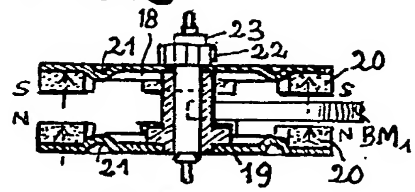


FIG.4

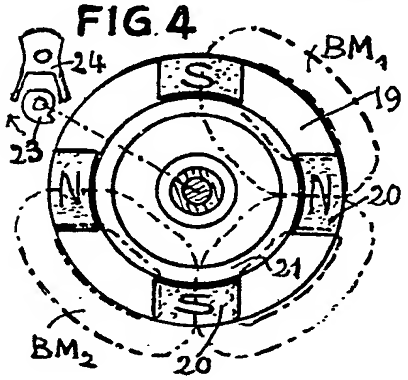


FIG.5

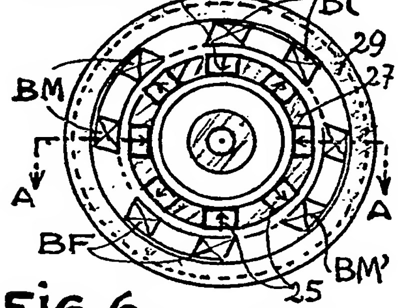


FIG.6

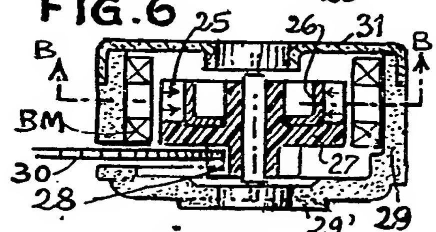


FIG.7

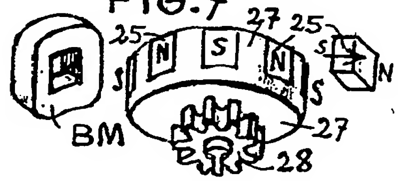


FIG.8

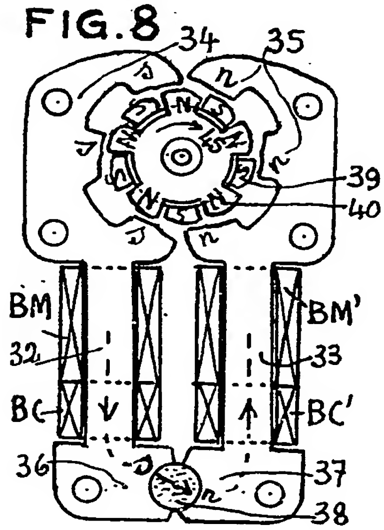


FIG.9

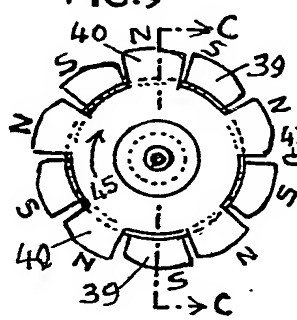
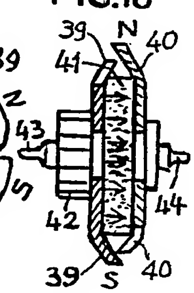


FIG.10



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Sheet 3

FIG.11

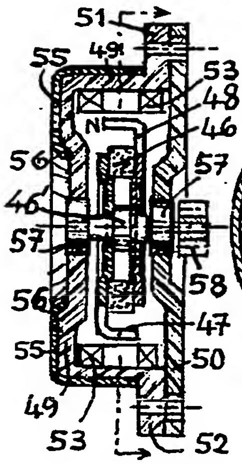

FIG.12

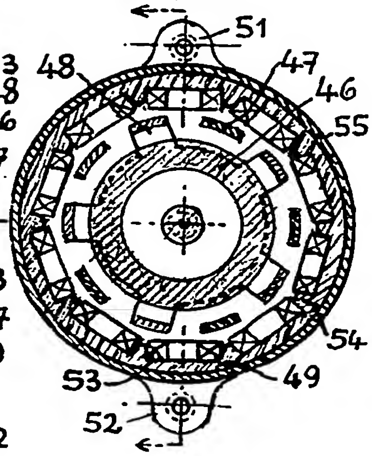

FIG.13

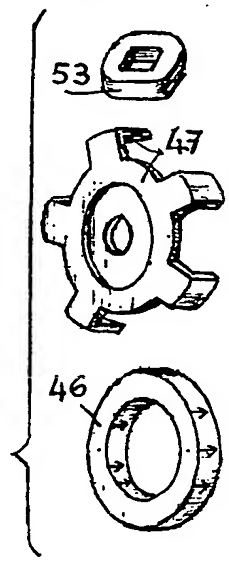

FIG.14

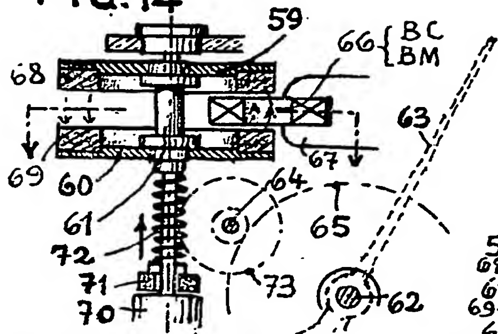

FIG.15

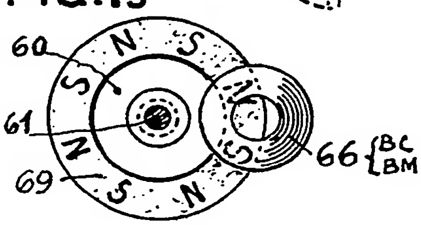

FIG.16

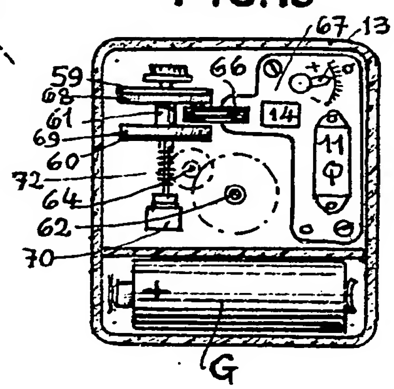

FIG.17

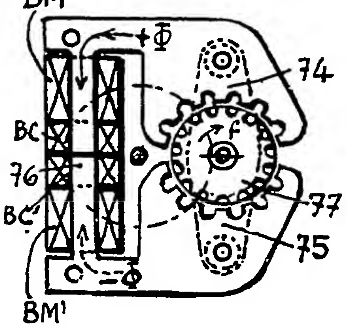

FIG.18

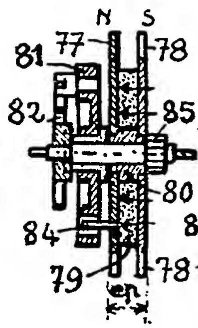

FIG.19

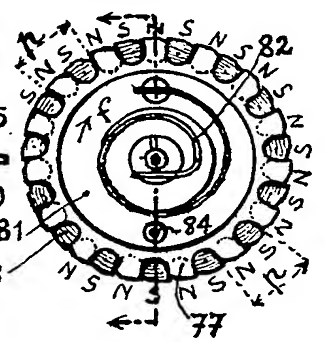

FIG.20